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# APPLICATION OF GIS FOR MAPPING OIL CONTAMINATED SOIL IN KUWAIT

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## Abstract

Contamination of the environment in Kuwait occurred in 1990-1991 during the Iraqi invasion and due to explosion of more than 700 oil wells. Oil contamination caused serious damage to the environment. This study was conducted to estimate the extent and volume of contaminated soil by using remote sensing, GIS application and field survey. A map of the area was developed by GIS showing four types of oil contaminations these are: liquid oil, oily soil, tar mat and soot plus a clean soil type, where no oil contamination was observed. Based on the three damage categories, the volume of contaminated soil was estimated at about 24.4 million cubic meters. The bulk of the oil-contaminated soil occurs in the dry oil lake areas (70%) and the oil lake areas (24%), and oily soil is the dominant type of contaminated soil layer. The application of remote sensing and GIS technology provided a tool to estimate the extent of environmental damages due to large scale oil pollution.

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**Keywords:** GIS, mapping, soil classification, soil survey, environmental assessment, oil pollution.

## Introduction

Geographical Information Systems (GIS) and databases are widely used in natural resources management and environmental science (Chansheg He 2003, Mennis 2006, Brown et al 1998). Long-term impact of oil pollution on the environment of Kuwait has been assessed in this study to determine the extent and volume of damage by remote sensing and GIS application. Oil contamination in the terrestrial environment of Kuwait occurred from the detonation of more than 700 oil wells that caused the following: 1) Oil spreading over the land surface and penetrating the soil to varying depth, 2) Aerial fall out from oil spray and combustion products from oil fires, and 3) Formation of oil lakes on the land surface. An estimated 2 million barrels of oil escaped from the damaged wells daily (PAAC 1999) Approximately 300 oil lakes of various sizes were estimated to cover more than 49 square kilometers of the land surface in Kuwait (Al-Ajmi et al. 1994, El-Baz et al. 1994, Kwarteng 1998). The majority of the lakes and oil-polluted surfaces were created in the Greater Al-Burqan oil field and surroundings (Salam 1996).

The intention is to manage and restore this contaminated land. The first step, therefore, is to know the location of as well as types and volumes of contamination present. Only with this knowledge can the land use be planned and remediation options considered.

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Previous studies showed that remote sensing has been the main tool used for estimating the area and extent of contamination and to monitor changes with time. Area estimates of oil lakes in the Greater Al-Burqan area range from 14.07 km<sup>2</sup> (Al-Ajmi et al. 1994) to 35.45 km<sup>2</sup> (Kwarteng 1998) and 24.14 km<sup>2</sup> (Kwarteng 1999). The large variation in results is due to the different techniques employed, each with different accuracies, and also to the inherent dynamics of the oil lakes as they dry, seep away, and are covered by a sand veneer. Furthermore, the accuracies of these estimates, both of area and volume, are unknown because there has been limited ground truth data.

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To estimate total volume of contaminated soil requires knowing both the area and average contamination depth of each lake. Whilst previous studies have characterized and quantified the contamination for specific sites (Al-Sulaimi et al. 1993, Zaman & Alsdirawi 1993, Balba et al. 1998), they have not estimated area and depth with sufficient accuracy and in any case too few sites have been studied to allow accurate volume estimation for the entire oil field.

Thus a field survey was designed to provide the geo-referenced, ground-truth information on the volume and extent of contaminated soils in the Greater Al-Burqan oil field at a more intensive scale than previous studies. This information will be used to aid subsequent rehabilitation planning and monitoring, and to provide a basis for future detailed quantification surveys. Therefore the objectives of this survey were to: 1) categorize the types of damage, 2) map the extent of damage, and 3) estimate the volume of contaminated soil.

### Site description

Kuwait is situated in the northwestern corner of the Arabian Peninsula between latitudes 28°30'N and 30°05'N and longitudes 46°33'E and 48°35'E. The climate of Kuwait is characterized by extremely high temperatures during summer, short mild winters, high sunshine hours, low humidity and generally dry condition. The mean rainfall is 118 mm/year, mean temperature is 37.4°C and maximum mean temperature is 45°C. The area investigated in this study was the greater Al-Burqan oil field located in the south of Kuwait City. It is defined by the oil field perimeter fence and includes the Al Maqwa, Al Ahmadi and Al Burqan oil fields (Fig. 1). The area is 56,245 ha, which covers about 3.3% of the State of Kuwait. The Greater Al Burqan oil Field was selected as the study area because most of the damage occurred in this area. It is large in extent and the distribution of damage is complex, requiring that a sound methodology be established. There is a wide range of contaminated conditions in the area from oil lakes to relatively 'clean' soil by visual observance, and the contamination can vary markedly over short distances both spatially and with depth. Time constraints and available resources meant that a detailed study could not be conducted for the area, and therefore the approach was to provide a broad overview upon which future detailed surveys could use as a base.

Deleted: The Greater Al-Burqan oil field occurs south of Kuwait City and includes the Maqwa, Ahmadi and Burqan oil fields (Fig. 1). Kuwait is characterized by a desert-type environment with low

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### Method

To assess the magnitude of damage in the Greater Al Burqan Oil Field, information on the extent and type of damage is required. Therefore the sampling sites need to be selected to assess where oil contamination exists and to provide supporting quantitative and qualitative data to assist with mapping and characterization of the oil contamination. An approach based on soil survey concepts using GIS was adopted because this methodology is proven for mapping and providing information over a large area using a sparse site density and limited analytical data set (Soil Survey Division Staff 1993). This approach can efficiently draw on existing data sets of varying quality and combine them with the sampling data set to improve the quality of the output and to reinforce confidence in the final result. This multifaceted approach used several sources of information – field survey observation data, remote sensed imagery, existing mapped information, laboratory analytical data and laser-induced fluorescence measurements.

Key variables measured were contamination depth (by measuring at field sites), total petroleum hydrocarbon concentrations (TPH) (USEPA 418.1 method 1988), a measure of oil contamination using laser-induced fluorescence (LIF), soil color (Munsell colour chart), soil texture, soil consistency, landscape description (Soil Survey Division Staff 1993), and site location (using a geographical positioning system).

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Information used for mapping included remote sensed Landsat TM imagery acquired in March 1998 and IRS panchromatic data acquired in February 1998, Kuwait Oil Company map 'Oil Lake EOD clearance status 27/12/98', geo-referenced field site data and field survey observations. The map linework was placed on a hardcopy image map by visual interpretation of imagery and taking into account the field data information, the linework was then digitized into the GIS for area calculations and generation of the final map.

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Digital Landsat TM imagery acquired in March, 1998, and IRS February, 1998, panchromatic data was added to the Soil Information System of Kuwait. This digital data was combined in the GIS with other cultural features and a geo referenced grid to produce draft field working maps. Hardcopy imagery was also produced at 1:50,000 and 1:20,000 scales and used as a base maps on which to stratify the area for site selection. Sites were then systematically sampled at regular intervals along transects. Sites were also placed by surveyor experience where there were safety and access problems. There was approximately 1 site per 100 ha and the final map scale was 1:50,000. Sites occurred throughout the survey area with the higher density of sites occurring around the more contaminated locations. Very high densities of sites occurred at a few locations where oil lakes were studied and sampled in detail. No sites were located on the edges of the oil field near the fence or in the middle of the oil field as remote sensed data indicated that these areas had limited contamination and are easily mapped with the available information from adjacent sites. 'Clean' sites for comparison were located inside and outside the survey area, on similar soils and beyond the observed contamination area.

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A total of 564 sites were located, described and classified. At a subset of these sites, soil was sampled for total petroleum hydrocarbon analysis (112 samples from 34 sites) and laser-induced fluorescence data (200 samples from 46 sites) that provided a measure of oil contamination equivalence.

All data was entered into a database for analysis and map information was manipulated by a geographical information system (GIS). An Intergraph GIS with Windows NT Microstation and MGE (Oracle based) suite of software was used to process the mapped data and to conduct map analysis. The workstations were linked to a Hewlett Packard 10BaseT hub, which is in turn connected to the Kuwait Institute for Scientific Research (KISR) network. Network communications is based on the Windows network system and TCP/IP protocol (Roy and Grealish 2004).

The map shows polygons and each polygon identifies the class of contamination within it. Essentially, the map unit boundaries indicated where it is expected that there will be a marked change in the type of oil contamination, its level of concentration and depth. Map unit purity and variability was conducted to indicate how well the map units are placed to identify the location of each category of oil contamination. To conduct the purity analysis, the site classifications were compared with the map units that the site occurred in. Map purity calculation was very high for all map units, ranging from 79.7 to 100%. This indicated that the map units correctly cover most of the classified sites.

The methodology for data linkages is shown in Fig. 2. The area for each individual map unit was calculated using the geographical information system and then those in the same map unit category were summed together. The contaminated soil volume was calculated from the area measurements with multiplication by the mean contamination layer thickness that occurred for that map unit category. Application of GIS is essential to calculate the volume of contamination in this study.

## Results and discussion

The map unit categories along with five other miscellaneous map units were mapped at a scale of 1:50,000 and a reduced version of the map is presented in Fig. 3. The total area for each map unit category is presented in Table 1. The largest unit is soot, followed by 'clean', tar mat and dry oil lake. The oil lake map units, where the magnitude of damage is greatest, are generally small in size, often less than 1 ha. A large number of these small size oil lakes exist now due to the original large oil lakes being subdivided by oil recovery operations and infrastructure development. Surrounding these oil lake map units are the dry oil lakes where a thickness of oil-contaminated soil remains. Tar mat and soot map unit categories are large units that occur throughout the survey area.

The area measurements, combined with contaminated depth measurements (from 564 sites) in the map unit categories, provided an estimated average contaminated soil volume of 24.4 million m<sup>3</sup> (Table 1). Calculating a volume in this way has inherent errors, therefore, standard errors of the depth measurements were used to provide estimates of the upper and lower volumes, which produced a contaminated volume range of 20.8 to 28.1 million m<sup>3</sup>.

**Deleted:** The field survey identified four types of oil contaminated soil layers (soot, tar mat, oily soil, liquid oil), plus a 'clean' soil type. From the field evidence, it is clear that these contaminated layers can be separated using colour and consistence properties. Liquid oil is black and non-coherent, oily soil is dark brown to black with a moderate to slightly hard consistency, and tar mat is black with a hard consistency.¶

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The contaminated soil volume estimates (Table 1) show that the bulk of the contaminated soil occurs in the dry oil lake category (70%) and the oil lake category (24%). The oil lake map units cover a small proportion of the oil field (2%), however, they account for 24% of the contaminated soil volume. This is due to deep oil penetration into the soil in this map unit category. Even though the tar mat and soot map units are large in extent, they only comprise a small proportion of the total volume of contaminated soil (4% for tar mat and 2% for soot), because the depth of contamination into the soil of this area is very small (about 1 cm).

The type of contaminated soil is dominantly characterized as oily soil, which forms 84% of the contaminated soil volume (18% in the oil lake map unit and 66% in the dry oil lake unit). Liquid oil forms 6%, tar mat 8% and soot 2% of the total.

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## Conclusions

The database and GIS provided essential data set for interpretation of extent and type of damage from oil pollution in Greater Al Burqan area. The mean total volume of oil-contaminated soil was estimated at 24.4 million cubic meters. The bulk of the contaminated soil occurs in the dry oil lake areas and oil lake areas, and oily soil is the dominant contaminated soil layer type.

Analytical results alone will not identify the different types of oil contaminated soil layers. Therefore, field observation is essential to the classification as these oil-contaminated layers have different characteristics and require different remediation or land use options (e.g. liquid oil has a weak consistency and tar mat has a very firm consistency).

The data gathered and interpreted by GIS application provides an overview of the contaminated soil characteristics and extent that can now be used as a basis for conducting future more detailed surveys to improve the quantification of the oil damage extent and volume. The data also provides base information to be used for land use planning and strategic decisions concerning remediation.

Deleted: This soil survey approach has been conducted on a large scale to determine the magnitude of soil damage in the Greater Al-Burqan oil field.

The data collected, computer database and geographical information system established in this survey is flexible and can be strategically updated with new information. This accurately located, primary information is readily retrievable for subsequent interpretation and further analysis.

Deleted: For remediation the bulk of the contaminated soil to be dealt with has oily soil characteristics, and in some areas the oily soil is under liquid oil that would also need to be ameliorated. In addition, all of these areas may contain unexploded ordnance. Any method for remediation of the tar mat and soot would need to take into account that they occur over an extensive area and form a thin layer on the soil surface.¶

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**Table 1. Map unit category areas and estimates of the contaminated soil volume**

Map unit Category	Area		Volume (million m <sup>3</sup> )			
	(ha)	(%)	Mean	(%)	Lower bound*	Upper bound*
Oil lake	983	1.8	5.8	23.8	5.2	6.4
Dry oil lake	7204	12.8	17.0	69.6	14.1	20.0
Tar mat	8508	15.1	1.0	4.1	0.9	1.1
Soot	20420	36.3	0.6	2.5	0.6	0.6
Clean	17035	30.3	ND**	ND**	ND**	ND**
Other	2095	3.7	ND**	ND**	ND**	ND**
Total	56245	100	24.4	100	20.8	28.1

\* determined as +/- SE from depth data

\*\* not determined

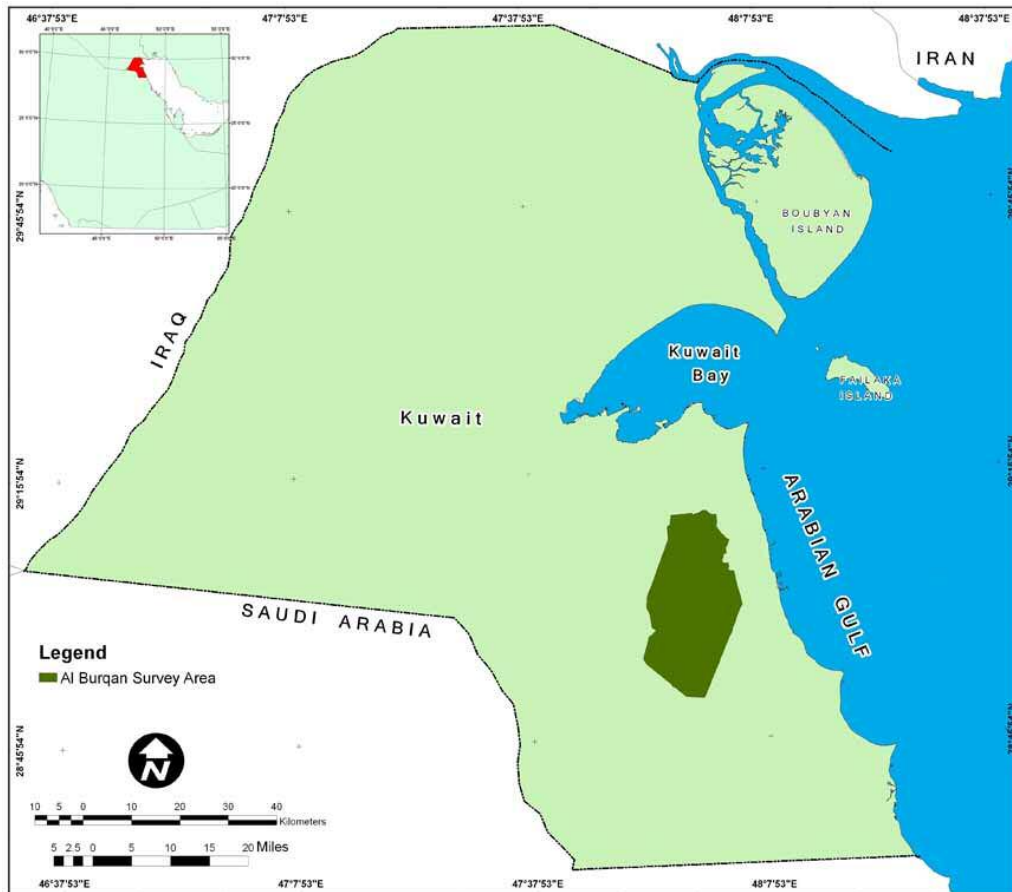
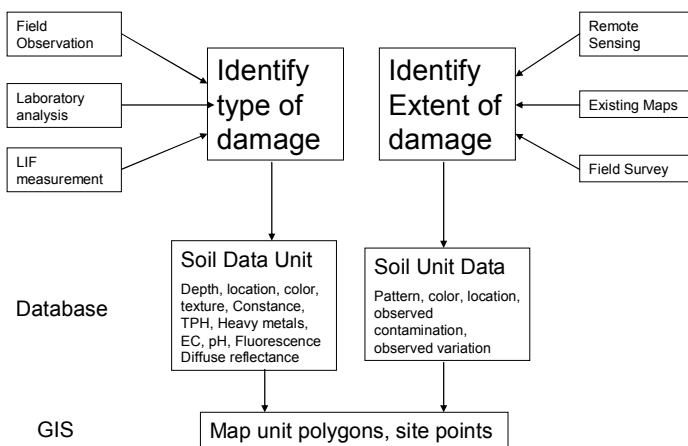


Figure 1. Location of Greater Al-Burqan oil field in Kuwait.



**Fig. 1. Methodology for database management and GIS application for assessing extent and magnitude of oil pollution in Greater Al Burqan Area, Kuwait.**

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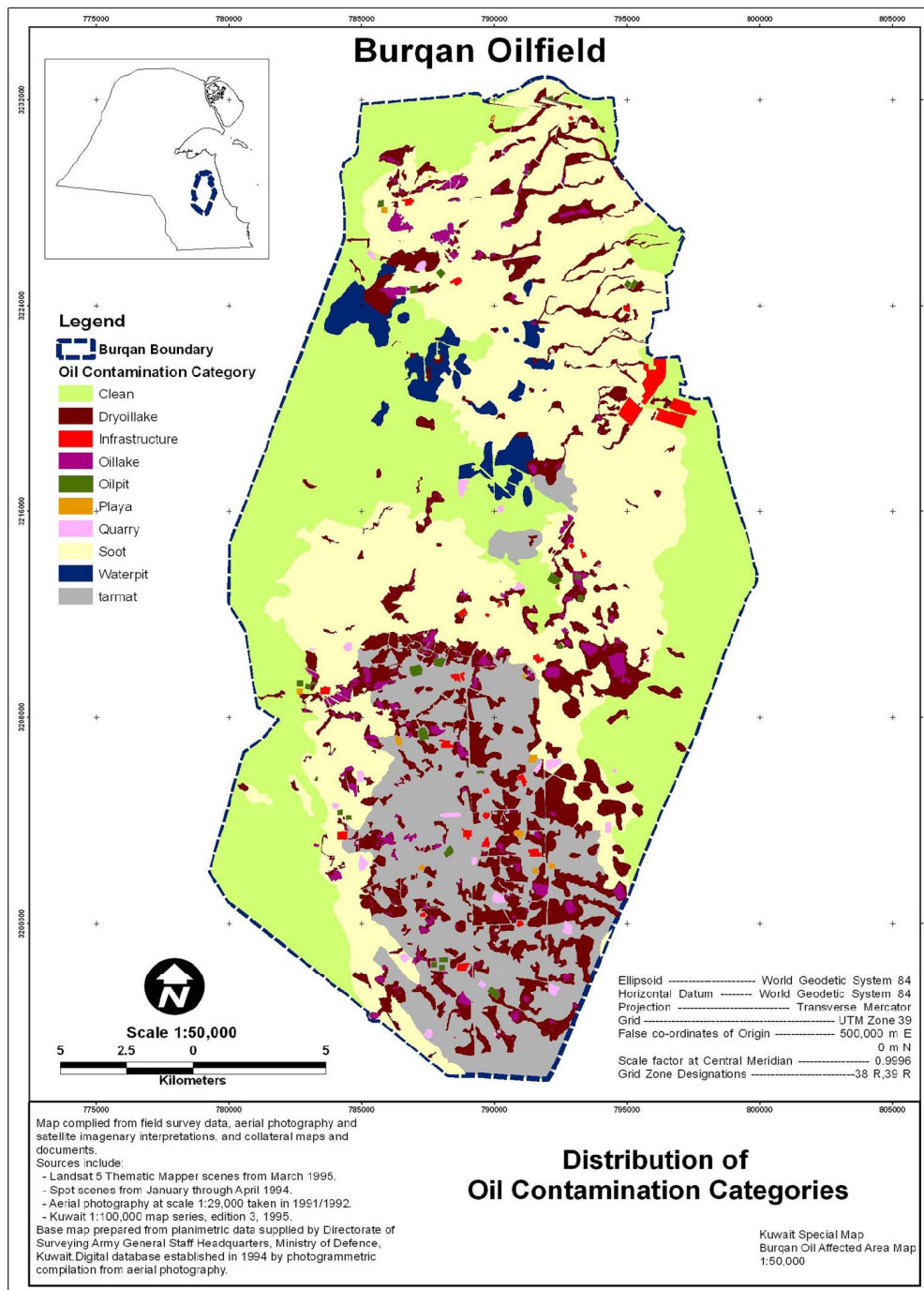


Figure 3. Reduced version of the 1:100,000 scale map showing distribution of the four oil contaminated map unit categories (oil lake, dry oil lake, tar mat, soot), a 'clean' map unit category, and five miscellaneous map unit categories (oil pit, water pit, quarry, infrastructure, quarry) in Greater Al Burqan Area in Kuwait.

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